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COMPARATIVE ANALYSIS OF METHODS FOR DRAWING GLASS FILAMENTS

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Mechanisms for drawing glass filaments used in the optical industry are considered. The drawing mechanisms are classified according to the type of transmission used to convert the rotary motion of the drive into the translational motion of filament drawn. The main reasons for nonuniform drawing velocities and deterioration of the quality of filaments are identified.

The process of drawing thin glass rods (filaments) from a heated glass melt is used in the production of optical fiber that has to meet stringent requirements with respect to the precision of geometrical sizes of the filament cross-section. Fibers are produced by drawing via an orifice or by redrawing from an intermediate bar, whose end is softened under the effect of temperature.

The stability of cross-section sizes of a rod drawn depends on numerous factors: the quality of the intermediate bar, the velocity of feeding the bar to the heating zone, the velocity of drawing heated glass melt, etc.

The uniformity of the drawing velocity is one of the main factors influencing the quality of the filament drawn. A preset drawing velocity is maintained by a drawing mechanism consisting of a drive and a transmission transmitting the rotary motion of the drive into the translational motion of the rod drawn.

The existing drawing mechanisms can be split into groups based on the type of transmission used to convert the rotary motion of the drive into the translational motion of the rod drawn, such as friction, belt, or screw-nut transmission, chain gear, or a combination of various types of transmission. One of the main criteria for selecting the type of drawing mechanism is its ability to ensure high uniformity of the drawing velocity.

The earliest ones were drawing mechanisms with friction gearing. Their performance is based on using friction forces arising at the site of contact of the body of revolution with the filament. In this case the drawing force

$$F_{\mathrm{d}} = Q f k^{-1}$$

is developed, where Q is the force of contraction of the bodies of revolution; f is the sliding friction coefficient; k is the engagement margin coefficient.

To avoid slipping, the contraction force should significantly exceed the drawing force: $Q = (10 – 15)F_{\mathrm{d}}$. On the other hand, the force Q should not exceed a permissible load applied to the rod. Therefore, friction transmission cannot ensure great drawing force. Furthermore, eccentricity of the bodies of revolution causes nonuniformity of the drawing velocity. Mechanisms with this type of transmission are mostly used to draw rods from melts.

In a drawing mechanism with a belt transmission a rod can be drawn by grips fixed on a belt or directly using two belts, whole pulleys revolve in different directions (Fig. 1).

The drawing force that can be provided by the belt transmission is

$$F_{\mathrm{d}} = 2S_0 \frac{e^{f\alpha} - 1}{e^{f\alpha} + 1},$$

where S_0 is the initial belt tension; f is the friction coefficient between the belt and the pulley; α is the angle encompassed by the pulley belt.

In a mechanism using two belts revolving in reciprocal directions, the filament may become twisted, and a certain shift of the belts may occur with respect to each other.

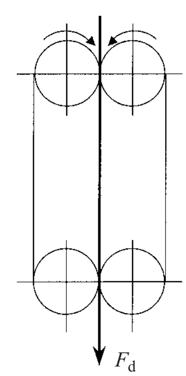

Fig. 1. Drawing mechanism with a belt transmission.

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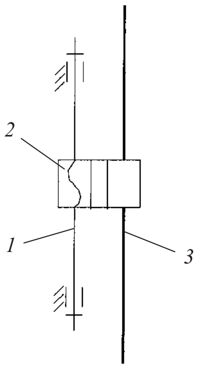

Fig. 2. Drawing mechanism with a screw – nut transmission.

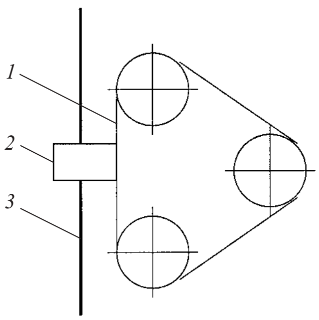

Fig. 3. Drawing mechanism with a chain trnsmission.

Elastic sliding in belt transmission is the reason for fluctuations in transmission. However, when the operating regime is close to idle running, elastic sliding is virtually equal to zero. Such regime can be implemented at $S_0 > 10F_d$. However, as the initial tension of the belt increases, its durability decreases. Furthermore, the belt becomes intensely stretched in operation.

The drawing mechanisms with a screw – nut transmission (Fig. 2) have a carriage *2* with grips fixed on a screw *1*. As the carriage moves, a filament *3* is drawn.

The screw transmission ensures a high accuracy of motion. A significant disadvantage of the screw – nut transmission is its high friction losses caused by high sliding velocities at the thread:

$$v_s = \frac{v_d}{\sin\psi},$$

where v_s is the sliding velocity; v_d is the filament drawing velocity; ψ is the thread helix angle.

Usually $v_s = (10 - 40)v_d$. High sliding velocities in this type of gear with a relatively low useful load inevitably cause fluctuations in the resistance force. This eventually leads to an unsteady drawing velocity.

Furthermore, these mechanisms have rather complex devices for switching the carriage with grips from working to idle stroke and vice versa. These switchings cause additional dynamic loads that are transmitted to the filament drawn.

The equipment for drawing filaments from intermediate bars successfully uses the screw – nut transmission in a mechanism feeding the intermediate bar into a furnace. The velocities here are lower by 2 – 3 orders of magnitude that those of the drawing mechanism. The whole cycle of drawing a filament from a single bar is performed in one working stroke of the nut.

Drawing mechanisms with a chain-and-sprocket transmission (Fig. 3) are quite common. These devices have one or two chains *1*, on which carriages *2* with grips are installed that draw a filament *3*. The purpose of the chain gear is to implement a forward motion of the carriage with the grips on the leading strand of the chain (working stroke) and return the carriage to the initial working position. During the working stroke the carriage runs into the master forms and the grips clamp the filament and draw it downwards. At the end of the working stroke the grips relax and free the filament.

The main factors that may cause nonuniform drawing velocities in such mechanisms are the polygonality of sprockets (the chain is arranged over a sprocket not as a circumference, but as a polygon), uneven sizes of chain links, and eccentricity of sprockets.

The polygonality of the sprocket results in an uneven drawing velocity estimated by the coefficient μ [1]:

$$\mu = 2\,\frac{1 - \cos(\pi / z_1)}{1 + \cos(\pi / z_1)},$$

where z_1 is the number of teeth in the drive sprocket.

Let $z_1 = 25$; then $\mu = 0.8\%$. As the number of teeth increases, μ decreases, but the gear sizes become larger.

As a consequence of imprecise manufacture or intense wear, the chains links may acquire different sizes. In this case the nonuniformity coefficient is equal to [2]:

$$\mu = 2\left[\frac{1 - \cos(\pi / z_1)}{1 + \cos(\pi / z_1)} + \frac{R_{max} - R_{min}}{R_{min}[1 + \cos(\pi / z_1)]}\right],$$

where R_{max} and R_{min} are the maximum and minimum radii of the chain joints on the sprocket teeth.

Let the wear be equal to 1%, i.e.,

$$\frac{R_{max} - R_{min}}{R_{min}} = 0.01.$$

Then if $z_1 = 25$, $\mu = 1.8\%$.

As can be seen from the above calculations, the wear of the chain links is a more significant reason for fluctuations in the cross-section size of the filament. This is confirmed as well by the practical experience of using factory-made chain transmission devices.

In the case of eccentricity of the sprocket, fluctuations in the drawing velocity are caused by periodic variations in the tension of the chain strands. The level of additional tension depends on many factors (the value of eccentricity, the rigidity of the chain, etc.) and may reach values close to the drawing force values.

The nonuniformity of the drawing velocity due to the factors mentioned above is of a periodic type. Thus, the perturbation frequency caused by the polygonality of the sprockets is equal to

$$f_r = \frac{z_1 n_1}{60},$$

where n_1 is the rotational speed of the leading sprocket, $\min^{-1}$.

The eccentricity of the sprockets causes a nonuniform drawing velocity with a frequency of $f_e = n_1/60$.

In order to determine the actual contribution of each factor to fluctuations in the filament diameter, variations in the diameter were constantly monitored and recorded during operation in an industrial drawing plant, which uses chain transmission as the drawing mechanism. Using harmonic analysis of the diameter deviation recorded along the filament length, the main harmonic components of diameter fluctuation were determined and their causes were identified. It was found that the main component of the fluctuation of the filament had a frequency of f_e. Furthermore, the level of the third harmonic is substantial (up to 40% of the first harmonic). The emergence of the third harmonic is related to the operation of the grips. The most critical moment in their operations is gripping the rod.

The factors causing nonuniform drawing velocities in different drawing mechanisms are listed below.

Transmission type used in drawing mechanism	Main factors causing nonuniformity of filament drawing velocity
Friction	Eccentricity of bodies of revolutions, slipping of filament between bodies of revolution
Belt	Elastic sliding of belts, stretching of belts in service
Screw – nut	Dynamic loads arising in switching the grips from working to idle running and back
Chain	Polygonality and eccentricity of sprockets, different sizes of chain links

The above data can be used in selecting a drawing mechanism. It should be taken into account that many of the reasons cited that cause nonuniformity of the filament drawing velocity are related to permissible drawing force values. For instance, these values for friction transmission should not exceed 10 N and for belt transmission not more than 100 N. Screw – nut and chain-and-sprocket transmissions should be used with high drawing forces ($F_d > 100$ N).

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